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Organic resources of the sea

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Despite the vast number of phyla and species in the sea, the major marine resource will continue to be fish for human consumption. At the same time, research on methods of preparing an animal protein concentrate, of high nutritional value and acceptable as human food, has pointed the way for the eventual development of a new technology.

Other bulk products of marine life-forms have been suggested as organic resources and include specific fatty acids and prostaglandins as therapeutic agents in human medicine as well as fatty alcohols and invertebrate chitin for industrial purposes. Only a few of the many options are considered here since the product must compete in terms of special properties, cost and availability with those derived from biomass of the land, industrial microbiology and from synthetic products made from fossil hydrocarbons.

Many biologically active chemicals have been isolated from marine life-forms, but only a few have been used as systemic drugs and selectively toxic agents (antibiotics) in human medicine. These and other chemicals that accumulate in marine organisms would illustrate that species survival in marine ecosystems have evolved specialized metabolic mechanisms that differ from those of terrestrial life-forms. Progress has been slow but it is with the nature and exploitation of these differences that future marine biological and biochemical research and development should be concerned.

INTRODUCTION

In contrast to the large and easily harvested green plants and herbivorous land animals, the unicellular phytoplankton, bacteria, protozoa and herbivorous zooplankton are microscopic in size and widely distributed in large volumes of seawater. Collecting these marine plants and animals by filtration may be desirable but it is impracticable with the possible exception of krill. It is only when large fish, at the top end of the food chain, aggregate or shoal during feeding, migration or spawning that significant amounts can be detected and harvested.

In the late nineteenth century, fish as a source of protein for human consumption was regarded as an infinite resource but today the annual world catch is not predicted to increase very much above the present level of about 70 Mt. For sea areas that are intensively fished it appears that for some species the maximum sustainable yield, set by basic photosynthetic production and the nature of the marine food chain, has already been achieved or exceeded – such as the decline of the herring industry in the seas around Britain (Steele 1980). The prediction does not take account of underexploited stocks since they are mainly not regarded as human or animal food. One exception may be the direct harvesting of Antarctic krill (*Euphausia superba*) with an estimated annual crop of about 20 Mt. The Antarctic Ocean is the world's most fertile ocean despite a low temperature and a short summer season. Nutrient-rich water from great depths wells up near the edge of the Antarctic continent and is considered to be the reason for the very high annual photosynthetic production (about 100 g carbon fixed per square metre per

[89]

year). It is not surprising that patches of feeding krill can be netted. However, even if krill are judged to be an economically feasible resource there will remain the difficult problem of defining an upper limit to the annual catch, consistent with the present revival of the whale population that feeds almost exclusively on krill.

The world catch of wild marine fish, as well as that from the mass culture of captive marine organisms, is still regarded primarily as a source of animal protein of high nutritional value to man. Filleting and other waste products, and surplus whole fish from a seasonal glut over demand are processed to fish meal and oils. Shellfish waste is usually discarded or dried and ground up as fertilizer. It is in this context that the present review attempts to discuss trends in science that are concerned with a more effective technological use of the products of the fishing industry as well as with the use of other marine organisms to provide essential biochemicals for the chemical and pharmaceutical industries.

MARINE PROTEIN AND OILS IN HUMAN AND ANIMAL NUTRITION

About 60% of the world catch of marine fish is used directly for human food. Waste from processing and substantial amounts of whole fish from species that for various reasons are not acceptable to man are processed to fish meal and oil. The annual yield can vary widely but orders of magnitude for 1977–8 are given in table 1.

TABLE 1. ANNUAL HARVEST (MEGATONNES) (1977) OF FISH USED MAINLY FOR PROCESSING TO FISH MEAL AND OIL

(Data from Stansby (1979) and Anon. (1977).)

species	total mass	oil
anchovy (Peru)	3.4	0.40
menhaden (U.S.A.)	2.4	0.20
capelin (Norway)	1.0	0.10
capelin (Canada)	0.8	0.08
sprats, etc. (U.K.)	0.8	0.08

Fish meal consists mainly of animal protein of high nutritional value and is extensively used as a dietary supplement in the food of omnivorous farm animals such as poultry and pigs as well as a major source of protein for mass-cultured carnivorous marine fish. Fish meal prepared from whole fish contains ground-up bones and scales. With oily fish it is difficult to express all the oil from the meal so that rancidity problems arise on storage. For these reasons, a potentially useful way to prepare a concentrated extract (Tatterson & Windsor 1974) involves the self-digestion of whole fish by their own or added digestive enzymes at an acid pH, and under conditions where the growth of bacteria is minimized. From this 'silage' process, insoluble debris such as bones were removed, the oil separated and recovered and the protein-peptide in the water extract used directly or indirectly as a feed supplement for animals. In the modification of this silage process used for Antarctic krill, critical factors are temperature and pH (Kolakowski *et al.* 1980).

In a world where there is an acute shortage of animal protein of high nutritional value, the whole business of feeding fish to farmed animals rather than directly to humans remains contentious. A fish protein concentrate or fish-flour suitable for human consumption would be a

desirable dietary supplement, particularly in regions where the amount of animal and other protein in the human diet is chronically below minimum nutritional requirements. Many solutions have been proposed, including a comprehensive research and development programme in 1960–70 supported by a government agency in the United States. The eventual process involved the removal of water and oil by azeotropic solvent mixtures. The bland powder produced was highly nutritious, but had to overcome human aesthetic and other prejudices (Pariser & Wallerstein 1980). Moreover, the procedures were difficult to apply in countries without a developed technology. To build on and extend this existing knowledge would be a desirable objective for science and technology in the foreseeable future where some emphasis is given to regional preferences and to the process of texturizing and flavouring – as has already been done with soya and other vegetable proteins.

As well as protein, oil is the major product in the processing of fish not used for human food (table 1). Marine oils are used in the manufacture of margarine and in animal food, and are an essential part of the food of cultivated marine fish. The use of marine oils for other industrial purposes is considered in the next section and for medical purposes in the penultimate section.

TABLE 2. INDUSTRIAL PRODUCTION OF FATTY ALCOHOL (MEGATONNES)

(Data from K. Coupland, personal communication.)

source	1981	1985
conversion from biomass oils	0.28	?
synthesis from petrochemicals	0.42	?
total	0.70	1-0

FATTY ACID AND FATTY ALCOHOLS IN MARINE OILS

The main constituents of natural oils (including vegetable oils) are glycerol and fatty acids. The latter are aliphatic acids with an even number of carbon atoms in a long chain of up to C_{22} . The acids may be saturated or unsaturated with a number of double bonds in the carbon chain. Catalytic conversion of natural oils to fatty alcohols is an important process in the chemical industry, and these alcohols have to compete in terms of price and availability with synthetic fatty alcohol made from ethylene by Ziegler and oxo processes, which use highly developed technology of the petrochemical industry (table 2). Both fatty acids and fatty alcohols have applications concerned with plastics, rubber, lubricants, detergents, textiles and cosmetics.

The catalytic conversion of natural oils to alcohols is an energy-intensive process involving high temperatures and pressures. Despite this, the overall cost of producing fatty alcohols from fossil hydrocarbon (ethylene) has increased at a rate greater than that of production from natural oils and is now reaching a point of equivalence. In the future it is generally accepted (Pryde 1979) that there will be a decline in the production of fossil-fuel based fatty alcohol in favour of a process based on a renewable bioresource. This trend would be even more marked if the high energy costs in the catalytic conversion of natural oils could be reduced, say by the use of enzymes as biocatalysts.

The fatty acid composition of marine oils varies with the species, time and space (Stansby 1979) but in general they have a longer chain length and are more unsaturated than the equally large resource of vegetable oils. Unsaturated fatty acids can be converted into shorter-chain acids that are also used as industrial raw materials.

To enhance the present supply of marine oils, a number of organisms may be considered but without more basic information it is not feasible to discriminate between the options. One obvious possibility is Antarctic krill as a source of oil (about 4%), protein and chitin, but it is not yet certain whether this potentially enormous resource is capable of being commercially harvested at an economic cost.

A further possibility would be the harvesting of marine organisms that already contain fatty alcohols in the body tissues. Wax esters (a fatty alcohol linked by an ester bond to a fatty acid) were first identified in 1970 by Lee, Nevenzel & Benson, at the Scripps Institution of Oceanography, as the major oil and metabolic fuel of many marine organisms such as some species of zooplankton and several species of mid-water and deep-water fish (table 3). It was suggested (reviewed by Sargent 1978) that in mesopelagic (mid-water) and bathypelagic (deep-water) regions of the seas there is a relatively low biomass, so that encounters between predator and prey are few and erratic. Predators therefore experience long periods of starvation and com-

TABLE 3. DISTRIBUTION OF WAX ESTERS IN MARINE ORGANISMS

(Numbers refer to individual species that have wax esters as major components of oil. Data from Lee *et al.* (1971), Sargent (1978) and Holz (1981).)

Protozoa		4	Chordata	sharks	1
Coelenterata	corals	3		teleost fish	
	anemones	5		bristlemouths	4
Ctenophora		1		coelacanth	1
Chaetognatha		1		deep-sea cod	2
Mollusca	squid	2		myctophids	8
Annelida	polychaete worm	1		escolars	2
Arthropoda	amphipods	5		mammals	
	copepods	33		sperm whale	1
	decapods	3		beaked whales	3
	euphausiids	3			
	mysids	3			
	ostracods	1			

pensate by accumulating large reserves of oil as a food store. Many mid-water and deep-water fishes have large stores of wax esters (table 3). The muscle tissue of one deep-sea fish contained 4.5% of an oil that consisted of 90% wax ester (Hayashi & Takagi 1980). For technical and economic reasons, these significant stocks are not exploited. Moreover, they are not really edible, since wax esters have a purgative effect on the gut of mammals including man (Mori *et al.* 1966). A commercial catch of zooplankton is made in the sheltered fjords of Norway (Wiborg 1976) and the annual world catch is estimated at 200 kt (Steele 1980). At the same time, a regular and large supply of marine oil containing equal amounts of a fatty alcohol and a fatty acid would find a ready market. One example is that a sulphurized oil rich in wax esters would find direct application as an additive to extreme high-pressure lubricants since the similar wax esters present in the blubber of the sperm whale were used for this purpose until 1970, when the sperm whale was placed on the list of endangered species. The central and most difficult question is whether the marine wax ester resource is large enough and accessible enough to be regularly cropped at an economic cost. It can only be answered by further study by marine and fisheries biologists in association with marine lipid biochemists. In particular, this would apply to exploratory work on new fishing grounds at depths of 550–1100 m on the continental slope to the west of the British Isles (Bridger 1978). Catch rates in several of these sea areas were

comparable with those made in what used to be traditional distant-water grounds. The species caught, such as grenadiers, black-scabbard, blue whiting and small sharks, would, however, be new to the British market.

In principle, the concept of mass culture of suitable marine organisms (e.g. zooplankton or fish) primarily for fatty alcohols for industrial use is attractive because the product would be reproducible and minimize a continued reliance on a harvest of wild organisms that can vary both in quality and quantity. As far as can be foreseen this possibility can be discounted simply on the scale of the operation that would be required.

The use of immobilized enzymes or cells as biocatalysts of the reactions concerned, with the conversion of oils to free fatty acids and fatty alcohols, is a possible and desirable alternative to the high energy costs of the catalytic conversion process. The enzymes or enzyme complex involved in the conversion have been identified in some of the marine and other organisms that use wax esters as an energy reserve and it remains to be established whether a reactor could be developed with the use of immobilized enzyme systems or cells. Although not directly relevant to the conversion of fatty acids to fatty alcohols, it has been shown that a bacterial suspension (100 ml of wet packed cells) suspended in 200 ml of carbon tetrachloride containing 10% cholesterol converted the substrate to cholesten-4-ene-3-one at a rate of 7 g h⁻¹ at 20 °C (Buckland *et al.* 1975). The cells could be separated readily from the organic solvent phase and reused several times with only a small decrease in enzymic activity. In a similar study the enzymic activity proved to be significantly more stable when the cells were entrapped in a gel matrix (Yamani *et al.* 1979). These examples suggest possible new approaches for the enzymic transformation of water-insoluble reactants in non-aqueous systems.

GLYCEROL AND RELATED COMPOUNDS FROM MARINE ORGANISMS

Glycerol is a by-product in the conversion of marine and vegetable oils to soaps and in the industrial production of fatty alcohols. A shortfall in supply from this source over demand has been met by the chemical synthesis of glycerol from petrochemical intermediates (Lipinsky 1981). Glycerol has many industrial uses in products such as cosmetics, plastics and explosives.

Biochemical work on certain halophilic (salt-loving) photosynthetic marine algae suggests that these organisms may be cultivated in estuarine ponds or salt-lakes in arid environments for the production of glycerol, cyclitol, sorbitol and mannitol. For example the green alga *Dunaliella* affects the photosynthesis and accumulation of glycerol within the cell (up to 80% of dry cell mass) as a defence mechanism against the high external salt concentration of its environment (Ben-Amotz 1980). Some of the physical conditions for mass culture have been defined (Goldman *et al.* 1982) and this is one example of the way in which metabolic specialization by one marine species may be used to trap solar energy into a defined chemical product in significant amounts. Apart from its use in industry, glycerol is a useful intermediate for chemical transformation into other products in industrial fermentation.

CHITIN AND ITS DERIVATIVES

Chitin and chitosan, the partly acetylated polymers of the amino sugar glucosamine, are the major structural polysaccharides in the integument of arthropods, the exoskeleton of crustaceans and in the cell walls of yeast and fungi (table 4). Although present research is at an early stage of development, the wide-ranging reports presented at a recent symposium (Muzzarelli

1978) would indicate that chitin may now be developed as a major biomass resource with application in many aspects of industry and elsewhere. In this context, the waste from shellfish processing contains up to 30 % of chitin. Among the natural polysaccharides such as cellulose, alginates and starch, chitin–chitosan is unique in its basic properties. From a chemical point of view, the fully deacetylated product may be regarded as large polymeric molecule containing functional amino and hydroxyl groups.

TABLE 4. SOURCES OF CHITIN

(Data from Muzarelli (1978).)

material	range of concentration (percentage of dry mass)		
	ash	protein and oil	chitin
shellfish waste	25–50	25–50	14–35
zooplankton including krill	24	60	8
zooplankton waste	23	52	34
<i>artemia</i> sp. (cysts)	15	40	7
mussels, oysters, tc.	85–90	—	3–6
squid (whole)	—	75–95	1–2
fungi (mycelium)	—	25–50	10–25
insects (whole)	—	60–80	0–8

In the native state chitin exists in two and possibly three polymorphic forms. Like plant celluloses, chitins are insoluble in normal solvents but dissolve in strong acid and some hydro-trophic solvents to give viscous solutions. These solutions may be extruded into anhydrous solvents to form continuous filaments that can be cold-drawn to give added tensile strength in a manner akin to synthetic polymers. There is some evidence that chitin promotes wound healing and is non-allergenic but slowly degradable in mammals (Prudeen *et al.* 1970). For these reasons, monofilaments of chitin have been considered for use as surgical sutures (Austin *et al.* 1981).

Many of the proposed practical uses of chitin–chitosan involve a high molecular mass polymer that is prepared by chemical hydrolysis to remove some but not all acetyl groups and is soluble in weak organic acids. The conditions of hydrolysis are critical because complete hydrolysis results in a marked decrease in molecular mass. Gels, tough flexible films and fibres with a high tensile strength, can be formed from the large chitosan polymer and the evidence for potential use are in the treatment of waste water and various aspects of the plastic, food-processing, paper and adhesive industries. The use of chitosans as potentially valuable polymers in analytical biochemistry and in the abstraction of specific metals from fresh and salt water is discussed in the following section.

The potential for the use of chitin–chitosan seems promising, but at least some of the work was done on partly characterized products of uncertain origin. Further development of these ideas will perforce involve new and improved methods for the isolation and definitive characterization of these polymeric carbohydrates. In addition a possible species variation in the primary structure must also be considered and will involve the specificity of chitinolytic and proteolytic enzymes as well as physical and chemical procedures. Some degree of species heterogeneity between purified chitins from marine crustaceans has already been found (Brine & Austin 1981). Basic biochemical information about the biosynthesis, chemical nature and turnover time in the animal body as well as the eventual degradation of chitin by predators and micro-organisms on the sea floor would be relevant to marine biology and ecology as it would be to the

eventual applications of the biopolymer. Waste from shellfish, including krill and brine-shrimp, will remain a source of bulk chitin but the possibility of the culture of yeasts and fungi, particularly those strains selected by induced mutation to yield a desirable product, must be considered as an additional resource.

BIO-ORGANIC POLYMERS THAT COMPLEX METAL IONS

Sediment-forming materials with a large surface area in natural water, particularly clay minerals, amorphous silicic acids and bio-organic polymers, are capable of sorbing charged ions from solution and releasing other ions into solution (ion exchange). The mechanism is based on the sorptive properties of charged sites, where the balance of charges in the lattice accounts for the preferential sorption of specific ions. Additionally, fine-grained materials with a large surface area are capable of binding metal ions at the solid-liquid interphase as a result of intramolecular forces (absorption).

The importance of bio-organic polymers for the transport of metals in aquatic systems has been recognized for many years and is an important part of biogeochemistry. Humic acid is a generic term for complex polymers of variable and uncertain composition that can be obtained from the soil and from sediments in natural waters. Despite the additional complexities of metal speciation in aquatic systems, there have been many studies aimed at some understanding of the selective sorption of various metals with humic acids (see Mantoura *et al.* 1978) and other biopolymers such as chitosan. There is now some evidence that these particulate biopolymers may be of use in the abstraction of radioactive and other elements from effluent water and in the abstraction of valuable elements from seawater.

One example is the abstraction of uranium from seawater, where a feasible and economic procedure would serve to minimize the acute shortage that is predicted by the end of this century. The source of the biopolymer remains uncertain since humic acid (Wagener & Heitkamp 1980), live and heat-killed cells of bacteria, actinomycetes, yeasts, fungi and algae (Horikoshi *et al.* 1981), as well as other bacteria and yeasts (Strandberg *et al.* 1981), all complex uranium in significant amounts – in some cases up to 15 % of the dry mass of the cell or biopolymer. The rate of reaction is rapid, by absorption and ion exchange, possibly to polyphosphate groups on the surface of the cells or biopolymer, and the amount absorbed conforms to the Freundlich absorption isotherm. Uranium could be chemically removed and the biopolymer preparation reused. In one population of bacterial cells it was found that only 44 % contained detectable uranium as judged by electron microscopy (Strandberg *et al.* 1981), so that environmental or other means of genetic selection may enhance the efficiency of the strain for the abstraction of uranium. One interesting possibility (Wagener & Heitkamp 1980) is that porous blocks of humic acid of a suitable buoyancy in seawater could be immersed to a depth of about 300 m in an ocean current and then released to float slowly up to the surface. These equilibrated blocks could then be retrieved, chemically stripped of uranium and other metals such as silver and then reused.

Chitosan, the deacetylated derivative of chitin, has many potential uses as an anion-exchanger as the free amino groups (pK_a 6.3) form quaternary nitrogen salts in acidic solution. It has a low capacity for alkaline earth ions, does not dissociate neutral salts and is superior to many other synthetic polymers for the abstraction of metals of the transition series from salty water. Notably, it is claimed to be the most effective absorbent known for the abstraction of vanadium

(0.34 g VO^{2+} and 2.3 g VO_4^{3-} per gram dry mass of polymer (Muzzarelli 1978)). The orthovanadate anion (VO_4^{3-}) is the principle form of vanadium in aquatic systems in concentrations of about 10^{-7} to 10^{-8} mol l^{-1} , with higher concentrations in some industrial effluents (Grant & Sargent 1980).

Despite this potential, it remains to be established whether these metal-complexing natural biopolymers can be obtained in sufficient amount with consistent stability constants in their reaction with metal ions and other properties.

BIOCHEMICALS OF POTENTIAL IMPORTANCE IN MEDICINE

Our present armoury of drugs for the chemotherapy of man is mainly composed of either natural products of unusual chemical structure that can be isolated from terrestrial organisms or synthetic analogues of those products. In some cases it is known that the genetic expression and secretion of these secondary products of cell metabolism represent one mechanism of species survival in the highly competitive situations that can arise in natural ecosystems.

Despite the success of research into the detection and development of antibiotics and other drugs, there is now concern about the diminishing returns from a continued emphasis on the screening and reliance on terrestrial life as a source of new drugs and a slowly developing interest in marine life forms. This interest stems from the clinical use of a few drugs of marine origin and from the widely scattered scientific literature on bioactive substances produced by the vast and diverse range of marine life. The nature and function of such bioactive substances are part of marine biology and ecology, but some of these substances may prove to be of relevance to human medicine.

(a) Systemic drugs

Some products of marine organisms have potential as drugs that modify cell function and metabolism in man, with functions that can be variously described as neuroactive, cardioactive, cardiovascular and anti-tumour. In many cases the stimulus to evaluate for drug function has its origins in scientific work in ecological relations or in folklore. One of the most potent poisons known is tetrodotoxin (an aminoperhydroquinazoline), a constituent of the liver and gonads of the puffer (*Tetraodon* group) and other tropical fish. The flesh of the puffer is regarded as a great delicacy by Japanese gourmets and a chef's reputation depends entirely on the number of guests who remain alive after eating his food. A lethal dose is about $10 \mu\text{g kg}^{-1}$ body mass and tetrodotoxin is about 160 000 times more potent at blocking nerve conduction than cocaine. At very low dose levels tetrodotoxin is used clinically as a muscle relaxant, a pain killer and a local anaesthetic (Ogura & Mori 1968).

The possibility that unusual products of marine organisms would have selectively toxic action on tumour growth in mammals is being considered. Several such compounds have been identified, including a glycopeptide that is present in the clam (*Mercenaria mercenaria*) and is non-toxic to mice at therapeutic concentrations (Schmeer 1979) and ill-defined substances present in the tentacles of tropical polychaetes (Tabrah *et al.* 1970). The latter study tends to substantiate the claim of folklore that cooked tentacles of these polychaetes had a beneficial effect on certain forms of cancer. One potent antitumour drug has its origins in the discovery by Bergman in 1968 that the West Indian sponge, *Tethya crypta*, contained large amounts of an unusual nucleoside containing arabinose rather than ribose. The synthesis and testing of a large number of nucleosides containing arabinose led to the development of ARA-C (β -D-

arabinofuransoyl cytosine) as a potent inhibitor of mammalian cell growth used in the chemotherapy of cancers such as leukaemias. ARA-C and its derivatives are known to be slowly phosphorylated to the 5'-triphosphate and to inhibit DNA synthesis (Raetz *et al.* 1977).

In contrast to terrestrial and aquatic organisms, those in the sea contain organically bound halogens where bromine predominates. Bromo derivatives are found in bacteria, in red and green algae and in some marine invertebrates (Fenical 1981). As well as several anti-microbial agents (Shield & Reinhart 1980) there are reports (Kaul & Kulkarni 1978) that Dactylene (an acetylenic dibromo ether) from the sea-hare (*Aplysia dactylomela*) may have useful therapeutic potential in the treatment of mental disorders. It has no direct effect on the cardiovascular, respiratory or nervous systems of small mammals. However, it appears to act by minimizing the degradation of barbiturates used to induce sleep, permitting the use of smaller and safer doses of the barbiturate.

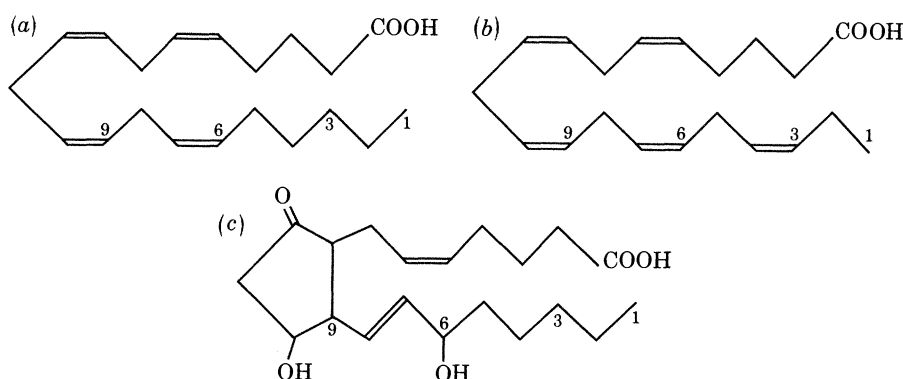


FIGURE 1. (a) Arachidonic acid (eicosatetraenoic acid, 20:4 ω 6), a fatty acid precursor of prostaglandins such as (c) prostaglandin PGE₂, in man; (b) eicosapentaenoic acid (20:5 ω 3), a major fatty acid in marine oils.

Prostaglandins and thromboxanes are very potent metabolic regulators in man that are formed by controlled enzymic reactions from unsaturated fatty acids with long carbon chains (figure 1). Normally, these potent regulators exist only in trace amounts in human tissue. Prostaglandins are required for the induction of labour and therapeutic abortion as well as in the treatment of diseases such as asthma and allergic hypersensitivity. Chemical synthesis of prostaglandins is possible but expensive. Natural prostaglandins are present in significant amounts in the slow-growing coral and in a faster-growing red alga (Gregson *et al.* 1979). The red alga is an abundant intertidal animal with a reasonable rate of growth and may be a suitable source of this potent material. In any event the rate-limiting enzyme in prostaglandin synthesis from unsaturated fatty acids, the endoperoxidase, has been identified in coelenterates and may be utilized for synthesis *in vitro* (Kayne *et al.* 1978).

The essential polyunsaturated fatty acids in the oils of land animals and plants are mainly of the ω 6 series, whereas those of marine organisms are mainly of the ω 3 series, predominantly eicosapentaenoic acid, EPA (20:5 ω 3), and docosahexaenoic acid (C22:6 ω 3). The methyl esters of these acids can be readily separated and isolated in gram quantity by high-performance liquid chromatography of fish oil preparations (Tokiwa *et al.* 1981). This procedure may now allow the evaluation of purified preparations of EPA as a supplement to the human diet as a potentially effective means for the prevention and treatment of thrombosis and arteriosclerosis.

This is a reasonable inference made from a long-term study of the beneficial effects of marine foods used in the aftercare of patients with heart conditions (Nelson 1972) and from an epidemiological study of an Eskimo population in Greenland (Dyerberg *et al.* 1978). There is also some experimental evidence that EPA is converted by the smooth muscle of arterial wall tissue to a prostaglandin-like substance (prostacyclin) that has a powerful anti-aggregation function for human platelets (Dyerberg *et al.* 1978). In contrast, the conversion of arachidonic acid (20:4 ω 6; see figure 1) to another prostaglandin-like substance (thromboxane A₂) is inhibited by EPA (Needleman *et al.* 1979). Thromboxane A₂ is a potent aggregator of human platelets. For these reasons, an antithrombotic state may be induced in man by a high dietary input of EPA, but the possible mechanism and an understanding of all the various biological functions of these prostaglandin-like substances at the level of the whole animal remains to be established.

An interesting area of disagreement concerns the possible therapeutic use of freeze-dried preparations of the green mussel (*Perna canaliculis*). This material is produced in tablet form in New Zealand and is selling briskly in health-food and chemists' shops all over Europe. It has the reputation, with limited medical evidence to support it, of being a possible alternative or supplement to orthodox therapy in the treatment of rheumatoid arthritis and osteoarthritis. Until more facts have been established it would be prudent to remain unconvinced about the health-enhancing properties of the green mussel (see Miller & Omerod 1980).

(b) *Antibiotics*

The classical example of the potential of marine organisms was the development by Abraham, Newton and Florey in the 1960s of the cephalosporin range of antibiotics that is produced by a strain of the fungus originally isolated from a marine sewage outfall. At about this time kainic acid (2-carboxy 4-isopropenyl 3-pyrrolidine acetic acid) was identified as the active principle in a red alga, *Digenea simplex*. Kainic acid is now a potent antihelminthic drug of low toxicity to man. Subsequently, extracts of many marine bacteria, fungi, planktonic and other algae have been found to be toxic towards the pathogens of man. More than 70 of these antimicrobial and antifungal substances have been isolated and chemically identified but in only a few and unsuccessful cases have their therapeutic potential been evaluated (Shield & Reinhart 1980). Generally, the objective of these studies was to characterize bioactive substances chemically rather than to search for clinically useful antibiotics. A deliberate screening programme, carried out in association with a pharmaceutical company who have long experience of similar work involving terrestrial organisms, would be a speculative but potentially rewarding area of endeavour. On the limited evidence available, microorganisms in the marine ecosystem secrete antibacterial and antifungal chemicals into their environment that are quite different from those in the soil habitat. Apart from its intrinsic interest to marine ecologists this probable difference has not been looked at systematically. This contrasts with the vast effort that has been expended on soil isolates as a source of antibiotics.

POSTSCRIPT

Marine science in Britain has a traditional and proper emphasis on biological oceanography and fisheries science that is concerned with the distribution of organisms in time and space, with their ecological interactions with each other in food chains and with the natural environment. It is only in recent years, partly due to the stimulus provided by the needs of fish farming and

the consequence of pollution, that experimental marine biochemistry, physiology and microbiology has been promoted on a significant scale. Knowledge about the basic biochemical principles of marine life forms has complemented and extended the concepts of oceanography and of fisheries science and is also relevant to resource development and utilization. However, this knowledge is minute when compared with that available on the genetics, molecular biology and biochemistry of land organisms including man, with applications in agriculture, medicine and fermentation and other industries. In a speculative review on biomass options to petrochemicals, Lipinsky (1981) does not consider marine options. In any event a marine resource will have to compete in terms of special properties, availability and cost with the corresponding material from land organisms and from the products of the petrochemical industry.

It is against this background that this review has been selective and attempts to present the case for a few specific areas where the potential is considered for the development or enhancement of a marine product in the foreseeable future. In the United States there appears to be some confidence in chitin as the Sea Grant Programme has provided funds for research and development (Austin *et al.* 1981). It is hoped that research policy in Britain will also seek to encourage biochemical and other research as a basis for the evaluation of these and other marine resources.

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